

# Scaling of Langmuir Circulation: Field Work of Opportunity

Dr. Jerome A. Smith  
8851 Shellback way, #354  
Scripps Institution of Oceanography  
La Jolla, CA 92093-0213  
phone: (858) 534-4229 fax: (858) 534-7132 email: [jasmith@ucsd.edu](mailto:jasmith@ucsd.edu)

Award Number: N00014-02-1-0855  
<http://jerry.ucsd.edu>

## LONG-TERM GOALS

The goal is to understand and parameterize the processes controlling exchanges between the air and ocean, across the ocean surface, mixed layer, and upper thermocline.

Langmuir circulation (LC) is an important coherent structure in the wind-mixed layer. Thus, for example, we wish to identify the important input parameters determining the characteristics of coherent structures such as LC, and to identify interactions with internal waves or fronts, and (finally) how these affect the physics, chemistry, and biology of the uppermost layer of ocean.

## OBJECTIVE

The objective is to determine the response of the surface mixed layer to known and hypothesized forcing. Known forcing terms include wind, waves, heat-flux, and shear across the thermocline. Newly hypothesized is an interaction between internal waves and LC leading to greater disorder in the LC flow structure. To address this hypothesis, data were sought from a location with both wind and strong internal wave forcing (e.g., near the Hawaiian mid-ocean ridge).

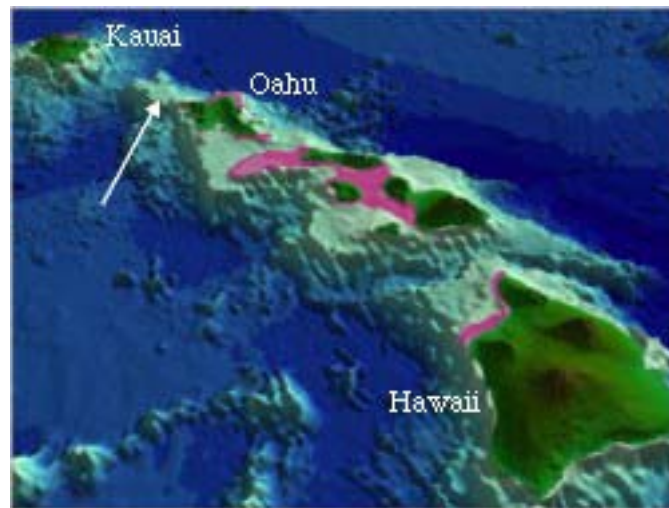
## APPROACH

The set of measurements needed to investigate mixed layer dynamics is extensive: wind and windstress, directional waves, wave breaking, stratification (density profiles), heat and moisture fluxes, and the mixed layer motions themselves, including indications of the spatial pattern (e.g. spacing and orientation of windrows) as well as strength (e.g., surface rms velocities). Of the necessary components, most were measured during the near-field leg of HOME (Hawaii Ocean-Mixing Experiment, Sept 9-Oct 21 2002). Measurements for HOME included CTDs (profiling temperature and density every 4 minutes to 800 m depth); a "deep-8" Doppler sonar (profiling the upper 800 m of the current structure), a sonic anemometer, and surface elevation (for wave height).

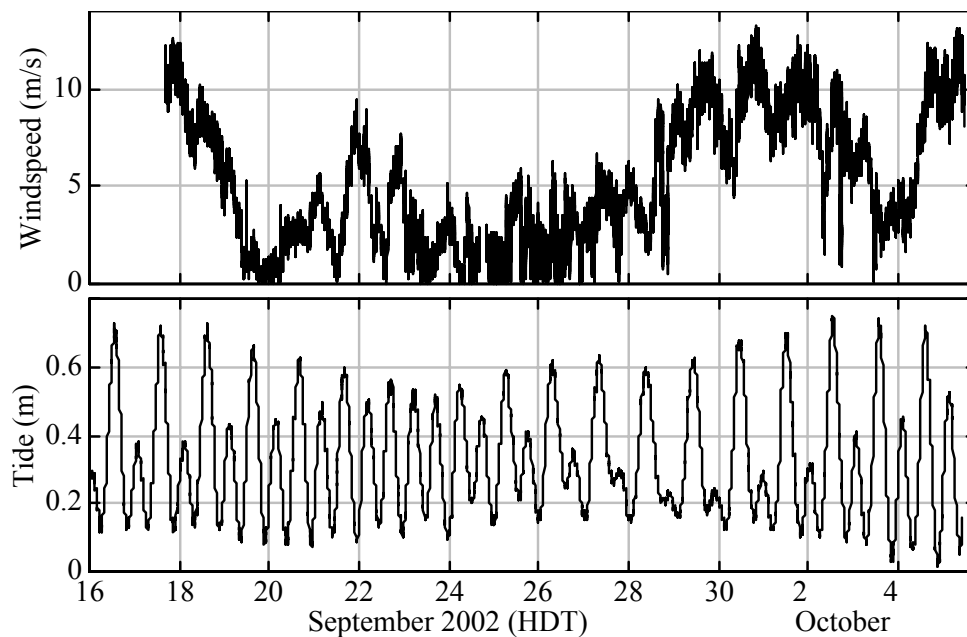
Leveraging this extensive suite of measurements, a new "long-range phased-array Doppler sonar" (LRPADS) was added to the FLIP deployment just west of Oahu, Hawaii (figure 1). Barotropic tides flowing NE–SW over the mid-ocean ridge there generate a strong baroclinic signal (internal waves). The setting for HOME, with both trade winds and strong internal wave forcing, represents a new environment relative to previous investigations of LC. During the experimental period, strong internal tides were evident, with moderate currents (0-40 cm/s) and winds (0 to 12 m/s; see figure 2). With 10

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 2003</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2003 to 00-00-2003</b>	
4. TITLE AND SUBTITLE <b>Scaling of Langmuir Circulation: Field Work of Opportunity</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Scripps Institution of Oceanography,,8851 Shellback way, #354,,La Jolla,,CA, 92093</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <b>The goal is to understand and parameterize the processes controlling exchanges between the air and ocean, across the ocean surface, mixed layer, and upper thermocline. Langmuir circulation (LC) is an important coherent structure in the wind-mixed layer. Thus, for example, we wish to identify the important input parameters determining the characteristics of coherent structures such as LC, and to identify interactions with internal waves or fronts, and (finally) how these affect the physics, chemistry, and biology of the uppermost layer of ocean.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES  <b>7</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

m resolution, and surveying an area  $\sim 1.5$  km in range by  $45^\circ$  in bearing, the LRPADS measurements of radial velocity and backscatter intensity permit examination of the near-surface expression LC, internal waves, and fronts, as well as the directional surface wave field. This data set provides new information concerning both parameterization of LC in terms of wind and wave forcing and possible interactions with the internal wave field.

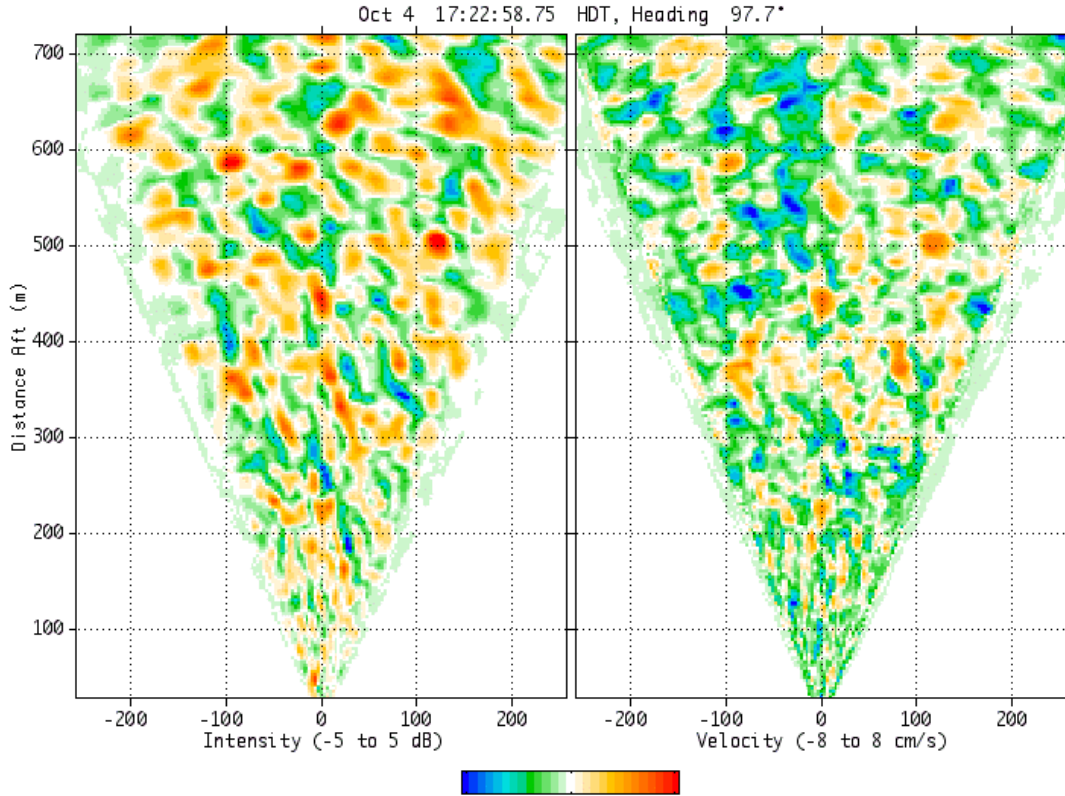


**Figure 1.** *The setting for HOME-Nearfield. FLIP was moored at the southern edge of the ridge just west of Oahu (white arrow). Barotropic tides flowing NE–SW over the ridge generate a strong baroclinic signal (internal waves). Trade winds are generally from the east.*



**Figure 2.** *(Upper panel) Windspeed at FLIP and (lower panel) tidal elevation at Honolulu during the operation of LRPADS in HOME-Nearfield. The period encompasses two spring tides and significant variability in windspeed.*

The analysis follows that of previous work: (1) simulate and correct for instrument response; (2) derive time-series of strength, spacing, orientation, and the various forcing parameters; (3) compare and correlate to test the hypotheses. In particular, a new consideration is the strength of internal wave straining at various scales.



**Figure 3.** *An example of the surface features seen during active Langmuir circulation. (Left) backscatter intensity, a measure of bubble density in plan-view. (Right) radial velocity, showing overall erratic patterns with some elongation in the same sense as seen in the intensity plot.*

The analysis plan (in more detail) is proceeding as follows:

*2D Timeseries.* Timeseries of the intensity and velocity fields from the LRPADS over the domain can be viewed as animations. With no averaging (a “snapshot” every 2.5 s) these reveal wave propagation and provide quality control feedback. Movies of 30 second averages reveal LC and the ultra-high-frequency end of the internal wave spectrum (“UHF-IWs”; e.g., figures 3, 4).

*Basic Timeseries.* Averages over 10 minutes or longer focus attention on time-scales appropriate to variations in wind, tides, and mixed layer depth. From the LRPADS data, area-mean surface velocity vectors can be extracted and compared to the wind vector and deeper velocities from the Deep-8 sonar.

*Advanced timeseries.* The flows of interest, and LC and UHF-IWs in particular, can be characterized by higher-order statistics. As in previous work [Smith, 1998], LC can be characterized in terms of an

RMS surface velocity (velocity scale); spacing between convergences (or mean wavenumber); orientation of the streaks (e.g., relative to the wind direction); and the degree of organization (or wavenumber bandwidth). Similar statistics can be generated for the UHF-IW field. The various forms of motion are isolated via their differing dispersion characteristics: LC propagates very slowly relative to the mean flow (less than 10 cm/s), while internal waves propagate at 1 m/s or faster. Surface gravity waves travel another order of magnitude faster. Thus, the three principle forms of motion can be separated via a full 3D Fourier analysis (2-space and time).

QuickTime™ and a  
PNG decompressor  
are needed to see this picture.

***Figure 4. Example frame as a high-frequency internal wave packet passes. (Left) Backscatter intensity; the mechanism by which the internal wave produces intensity contrast is not certain. (Right) Radial velocity component (roughly up/down). The waves propagate from upper left to lower right, towards the NE and hence toward the shallowest part of the ridge.***

## WORK COMPLETED

The LRPADS was deployed in collaboration with HOME, and LRPADS data were collected from 1500 9/14 (HDT) to 1130 10/5 (about 21 days total). LC (figure 3) and ultra-high-frequency internal waves (figure 4) were imaged clearly in the LRPADS data. Conditions ranged from dead calm to modest winds (~12 m/s). While the first two analysis steps above are essentially complete, the spectral separation and higher-order statistics analysis is still in progress.

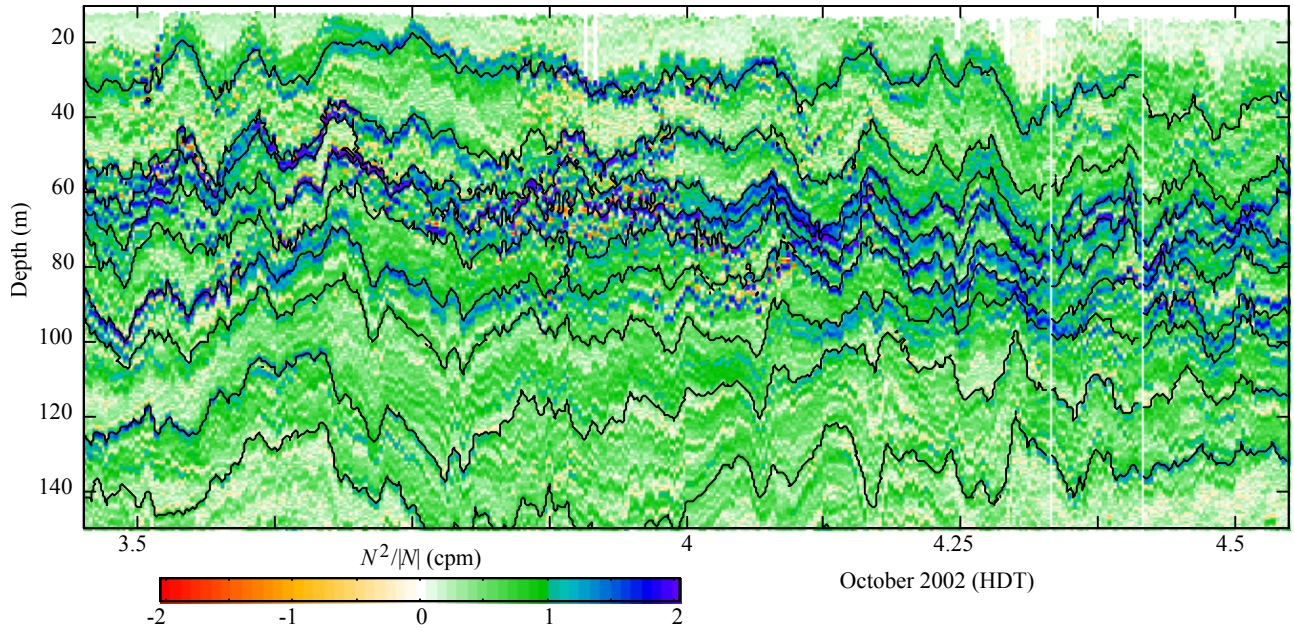
The UHF-IWs can only be supported in the sharp pycnoclines just below the mixed layer (figure 5).

## RESULTS

Langmuir circulation (LC) observed off Hawaii is unsteady, with "along-stripe" coherence lengths not much larger than in the "cross-stripe" direction. Work proceeds towards quantifying this in comparison to the levels of unsteadiness observed previously.

Time-depth plots of potential density or  $N^2$  indicate enhanced upper thermocline mixing (just below the mixed layer), loosely associated with the (strong) tides.

A significant finding is that, particularly during calm periods, ultra-high-frequency internal waves ("UHF-IWs" –with periods of a minute or less) produce surface velocity expressions of order 10 cm/s in amplitude. With wavelengths of around 200 m, this implies horizontal strain rates ( $du/dx + dv/dy$ ) of order  $10^{-3} \text{ s}^{-1}$ , which would dominate among internal-wave-induced strain rates in the mixed layer. These strain rates are only slightly smaller than for fully developed Langmuir circulation under 12 m/s winds. In the presence of such winds, however, such UHF-IWs are not evident. With comparable wavelengths and velocity scales, interactions between Langmuir circulation and UHF-IWs could be strong, which might help explain these observations. Careful analysis is needed to verify these results.



**Figure 5.** Buoyancy frequency  $N^2$  versus depth and time over one day. Blue contours indicate more than a cycle per minute (cpm)- higher frequencies than are found in the deeper portion (below 150 m). Red or orange “speckles” indicate overturns (statically unstable), which implies active mixing (see especially just before the 4<sup>th</sup> near 60 m depth).

## IMPACT/APPLICATIONS

Langmuir circulation (LC) is an important coherent structure in the wind-mixed layer (figure 1), with ramifications across marine disciplines: It can enhance deepening and inhibit re-stratification, altering the seasonal thermocline evolution, and hence the cumulative air-sea exchanges. Also, entrainment and organization of bubbles by LC introduces dramatic sound speed variability with spatial scales of

meters to 100's of meters, affecting sound propagation. Bubble subduction also affects gas dissolution and hence gas fluxes. Further, organization of seaweed and plankton in the surface layer is a first-order effect on the marine euphotic-zone ecology. Finally, dispersal of materials on the surface by Langmuir circulation is a major component of modern models for oil-spill tracking and abatement, and for search-and-rescue.

The ultra-high-frequency internal waves (UHF-IW) may play a role in mixing and overturns within the sharp upper pycnocline that forms just below the mixed layer. This is the only region where  $N^2$  is large enough to support such UHF-Iws. Thus, the shear and straining associated with them is confined to this region, so their total energy is focussed where it could add to or draw from the energy needed for mixing. It is also focussed near the mixed layer, so interactions can occur with LC.

## RELATED PROJECTS

PasSAS ("Passive Synthetic Aperture Sonar" experiment, ONR acoustics; W Kuperman, lead PI)- A multi-PI project to characterize the ocean environment sufficiently to assess the performance of passive synthetic aperture sonar. The Pinkel/Smith section focuses on characterizing waves, internal waves, and Langmuir circulation over an  $O(1.5 \text{ km})^2$  area of the ocean surface.

HOME ("Hawaii Ocean-Mixing Experiment," primarily NSF funded project). A multi-institution, multi-investigator field program investigating ocean mixing resulting from the conversion of barotropic to baroclinic (internal wave) tidal energy at a mid-ocean ridge. More information is available at <http://chowder.ucsd.edu/home/>

## REFERENCES

Smith, J.A., Evolution of Langmuir circulation during a storm, *Journal of Geophysical Research*, 103 (C6), 12,649-12,668, 1998.

Smith, J.A., Observations and theories of Langmuir circulation: a story of mixing, in *Fluid Mechanics and the Environment: Dynamical Approaches*, edited by J.L. Lumley, pp. 295-314, Springer, New York, 2001.

## PUBLICATIONS

Smith, J.A., Continuous time-space sampling of near-surface velocities using sound, *J. Atmos. Oceanic Tech.*, 19 (11), 1860-1872, 2002. [published, refereed]

Smith, J.A., The use of phased-array Doppler sonars near shore, *J. Atmos. Oceanic Tech.*, 19 (5), 725-737, 2002. [published, refereed]

Smith, J. A., and R. Pinkel, Long-range acoustic Doppler array measurements of surface velocities. IEEE Current Meter Technology Conference, San Diego, CA, March 2003. [Web publication: [http://jerry.ucsd.edu/LC\\_and\\_IW/LC\\_IW.html](http://jerry.ucsd.edu/LC_and_IW/LC_IW.html) ]

Smith, J. A., Observations of Langmuir circulation from FLIP. AGU fall meeting, December 2002. [converted to web publication: <http://jerry.ucsd.edu/LCfromFLIP/LCfromFLIP.html> ]